Chapter 3 SUMMARY

Key Expectations

- Explain the experimental observations and inferences made by Rutherford and Bohr in developing the planetary model of the hydrogen atom. (3.1, 3.2, 3.3, 3.4)
- Describe the contributions of Planck, Bohr, Sommerfeld, de Broglie, Einstein, Schrödinger, and Heisenberg to the development of the quantum mechanical model. (3.3, 3.4, 3.5, 3.6, 3.7)
- Describe the quantum mechanical model of the atom. (3.5, 3.6, 3.7)
- Use appropriate scientific vocabulary to communicate ideas related to atomic structure sections. (all)
- Write electron configurations for elements in the periodic table, using the Pauli exclusion principle and Hund's rule. (3.5, 3.6)
- Describe some applications of principles relating to atomic structure in analytical chemistry and medical diagnosis. (3.8)
- Describe advances in Canadian research on atomic theory. (3.2, 3.7, 3.8)

Key Terms

absorption spectrum
actinides
aufbau principle
bright-line spectrum
electron configuration
electron probability density
Heisenberg uncertainty principle
Hund's rule
isotope
lanthanides
magnetic quantum number, m_l
neutron
orbital
Pauli exclusion principle
photoelectric effect
photon
principal quantum number, n
proton
quantum
quantum mechanics
representative elements
secondary quantum number
shell
spectroscopy
spin quantum number, m_s
stationary state
subshell
transition
transition elements

Key Symbols

- $E, n, l, m_l, m_s, s, p, d, f$

Problems You Can Solve

- Determine possible values of the four quantum numbers. (3.4)
- Write electron configurations for atoms of elements in the periodic table. (3.5).

MAKE a summary

- The following chart is intended to summarize the key experimental work that directly led to major steps in the evolution of atomic theories. Copy and complete this chart.

Atomic theory	Key experimental work	Contribution to theory
Rutherford		
Bohr		
Quantum Mechanics (including initial development of quantum numbers)		

- Many scientists contributed to the development of the quantum mechanical model of the atom. For each of the following scientists, state one significant contribution.

  Planck, Bohr, Sommerfeld, de Broglie, Einstein, Schrödinger, Heisenberg

- (a) Sketch an outline of the periodic table and label the *s*, *p*, *d*, and *f* blocks of elements.
  (b) What is the empirical justification for this labelling?
  (c) What is the theoretical justification for this labelling?

Chapter 3 SELF-QUIZ

Identify each of the following statements as true, false, or incomplete. If the statement is false or incomplete, rewrite it as a true statement.

1. The region in space where an electron is most likely to be found is called an energy level.
2. Electron configurations are often condensed by writing them using the previous noble gas core as a starting point. In this system, [Ar] $3d^3 4s^2$ would represent calcium.
3. The *f* sublevel is thought to have five orbitals.
4. Orbital diagrams generally include the region of space in which the electron may be found most of the time.
5. For some alpha particles to be reflected backward by a gold nucleus in Rutherford's experiment, the gold nucleus had to be both very massive and strongly positive.
6. Rutherford knew the nucleus had to be very small because most alpha particles were deflected when fired through a layer of gold atoms.
7. Electrons shifting to higher levels, according to Bohr, would account for emission spectra.
8. Elements with atomic electron configurations ending in np^5, where n is an integer from 2 to 6, are called the halogens.
9. Photon is the term used to refer to a quantum of electromagnetic energy.
10. The serious shortcoming of Bohr's theory was failure to predict spectra for atoms other than hydrogen.
11. The Pauli exclusion principle states that two electrons may not occupy the same energy level.

Identify the letter that corresponds to the best answer to each of the following questions.

12. Rutherford's classic experiment produced evidence for a nuclear atom model when atoms in a thin metal foil scattered a beam of
    (a) cathode rays. (d) electrons.
    (b) alpha particles. (e) protons.
    (c) X rays.
13. Max Planck's mathematical explanation of blackbody radiation required that he assume that, for atoms
    (a) most of the mass is in a tiny part of the volume.
    (b) electrons orbit the nucleus as planets orbit a star.
    (c) electrons have several different energy levels.
    (d) the energy of the vibrating atoms is quantized.
    (e) all of the positive charge is located in the nucleus.
14. Niels Bohr assumed that when a photon is released from an atom to produce a bright line in the spectrum,
    (a) an electron has dropped from a higher energy level to a lower one.
    (b) the atom must have returned to its ground state.
    (c) an electron has been converted into emitted energy.
    (d) the electron has both wave and particle properties.
    (e) the energy of the atom has increased one quantum.
15. If the ground-state electron configuration of an atom is [Ne] $3s^2 3p^4$, the atom is
    (a) magnesium. (d) argon.
    (b) silicon. (e) selenium.
    (c) sulfur.
16. Which of the following will **not** have an electron configuration ending with $3s^2 3p^6$?
    (a) chloride ion (d) calcium ion
    (b) sulfide ion (e) potassium ion
    (c) aluminum ion
17. Which of the following is **not** used to determine an electron configuration for an atom?
    (a) Hund's rule
    (b) Heisenberg's uncertainty principle
    (c) Pauli's exclusion principle
    (d) the aufbau principle
    (e) the periodic table
18. Which of the following statements is *false*, based upon your knowledge of electron configurations?
    (a) Iron is ferromagnetic; copper is paramagnetic.
    (b) The sodium ion is formed by the sodium atom losing one *s* electron.
    (c) The silver atom has an electron promoted from the 5*s* to a 4*d* orbital.
    (d) The manganese atom has one electron in each 3*d* orbital.
    (e) The tin(IV) ion is formed by the tin atom losing two *p* electrons and two *d* electrons.
19. The contribution of Erwin Schrödinger to the quantum mechanical atomic model was
    (a) a theoretical prediction that particles should exhibit wave properties.
    (b) a theoretical principle that precision of measurement has an ultimate limit.
    (c) an explanation of the photoelectric effect utilizing an energy quantum.
    (d) a mathematical description that treats electrons as standing waves.
    (e) experimental verification of the quantization of charge.

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Understanding Concepts

1. Scientific theories are usually developed to explain the results of experiments. Describe the evidence that the following scientists used to develop their atomic models. Include the main interpretation of the evidence.
   (a) Rutherford
   (b) Bohr (3.4)
2. When a theory is not able to explain reliable observations, it is often revised or replaced. The Rutherford and Bohr atomic models represent stages in the development of atomic theory. Describe the problems with each of these models. (3.4)
3. State a similarity and a difference between the terms "orbit" and "orbital." Which atomic models that you have studied would use each of these terms? (3.5)
4. What was the main kind of experimental work used to develop the concepts of quantum mechanics? (3.5)
5. The quantum mechanical model of the atom involves several theoretical concepts. Describe each of the following concepts:
   (a) quantum
   (b) orbital
   (c) electron probability density
   (d) photon (3.7)
6. The Pauli exclusion principle states that no two electrons in an atom can have the same set of four quantum numbers. Draw an energy-level diagram for the ground-state oxygen atom and label the features that provide the following information.
   (a) the main/principal energy level
   (b) the energy sublevel (subshell)
   (c) the orientation of an orbital
   (d) the spin of the electron (3.6)
7. What evidence indicates that electrons have two directions of spin? (3.6)
8. Draw an outline of the periodic table and label the sublevels (subshells) being filled in each part of the table. (3.6)
9. According to quantum mechanics, how does the position of an element on the periodic table relate to its properties? (3.6)
10. Complete energy-level diagrams for potassium ions and sulfide ions. Which noble gas atom has the same diagrams as these ions? (3.6)
11. (a) What are some similarities in the chemical properties of alkali metals?
    (b) How is this explained theoretically, using concepts in this chapter? (3.6)
12. Write a complete ground-state electron configuration for each of the following atoms or ions:
    (a) Mg
    (b) S^{2-}
    (c) K^{+}
    (d) Rb
    (e) Au (3.6)
13. Write the shorthand electron configuration for each of the following atoms or ions:
    (a) yttrium
    (b) antimony
    (c) barium ion (3.6)
14. Paramagnetic substances are attracted by a magnet. Indicate which of the following elements are paramagnetic. Justify your answer.
    (a) aluminum
    (b) beryllium
    (c) titanium
    (d) mercury (3.6)
15. Identify the following atoms or ions from their electron configurations:
    (a) W: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^3$
    (b) X^{+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6$
    (c) Y^{-}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6$
    (d) Z: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6\ 6s^2\ 4f^{11}$ (3.6)
16. Calculate the maximum number of electrons with the following principal quantum numbers, n:
    (a) 1
    (b) 2
    (c) 3
    (d) 4 (3.6)
17. Sketch the shape of a $2p_x$ orbital. How is this orbital the same as and different from the $2p_y$ and $2p_z$? (3.7)
18. The quantum mechanical model of the atom has been called "the greatest collective work of science in the 20th century," because so many individuals contributed to its development. Briefly describe the contributions of each of the following scientists:
    (a) Max Planck
    (b) Louis de Broglie
    (c) Albert Einstein
    (d) Werner Heisenberg
    (e) Erwin Schrödinger (3.7)
19. A scientific concept can be tested by its ability to describe and explain evidence gathered by scientists. Use the concepts created in this chapter to describe and/or explain the following observations.
    (a) The very reactive metal sodium (it even reacts with water) reacts with chlorine (a reactive poisonous gas) to produce inert sodium chloride (table salt that we eat).
    (b) The flame test for lithium produces a red flame while that of sodium is yellow.
    (c) Sodium chloride and silver chloride have similar empirical formulas, $NaCl_{(s)}$ and $AgCl_{(s)}$.
    (d) The empirically determined formulas for the chlorides of tin are $SnCl_{2(s)}$ and $SnCl_{4(s)}$. (3.7)

Applying Inquiry Skills

20. Using what you have learned in this chapter, state why the evaluation of evidence is such an important part of the scientific process. (3.7)
21. An unknown substance appears on the surface of a city's water reservoir (**Figure 1**). What are some experimental techniques that could be used to help identify the substance? (3.7)

Figure 1

22. Critique the following experimental designs. Suggest better designs to meet each purpose.
    (a) A gaseous element is identified from a discharge tube by observing the visible and infrared spectrum through a hand-held spectroscope.
    (b) A mixture is identified by conducting a flame test.
    (c) The presence of iron in iron-fortified breakfast cereal is tested by taping a strong magnet to the outside of a half-full cereal box and shaking the box.
    (d) The paramagnetism of the element calcium is tested by determining the effect of a magnet on a saturated solution of calcium sulfate in a small test tube suspended by a thread. (3.6)
23. Critique the following analogies, physical models, or simulations.
    (a) Climbing a staircase is used as an analogy for the transition of electrons to different energy levels in an atom.
    (b) A computer simulation for plotting the 1*s* orbital of the hydrogen atom is used to test the quantum/wave mechanical model of the atom. (3.7)

Making Connections

24. Medical diagnosis has benefited substantially from advances in our understanding of the atom.
    (a) State three or more examples.
    (b) Provide some positive and negative arguments, from at least three perspectives, about government support of fundamental research. (3.8)
25. Ernest Rutherford and Frederick Soddy collaborated in researching radioactivity at McGill University (1900–02). Their empirical work completely transformed the understanding of radioactivity, and earned each of them a Nobel Prize.
    (a) Research their Nobel Prizes and report on the year of the award, the subject area, and specific contributions cited.
    (b) Describe the effects of their discoveries on our society. (3.8)

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Chapter 4 SUMMARY

Key Expectations

- Explain how the Valence-Shell-Electron-Pair-Repulsion (VSEPR) model can be used to predict molecular shape. (4.3)
- Predict molecular shape for simple molecules and ions, using the VSEPR model. (4.3)
- Predict the polarity of various substances, using molecular shape and electronegativity values of the elements of the substances. (4.4)
- Explain how the properties of a solid and liquid depend on the nature of the particles present and the types of forces between them. (4.4, 4.5, 4.6)
- Predict the type of solid (ionic, molecular, covalent network, or metallic) formed by a substance, and describe its properties. (4.6)
- Conduct experiments to observe and analyze the physical properties of different substances, and to determine the type of bonding that contributes to the attraction between molecules. (4.4, 4.5, 4.6)
- Describe some specialized new materials that have been created on the basis of the findings of research on the structure of matter, chemical bonding, and other properties of matter. (4.6)
- Describe advances in Canadian research on atomic and molecular theory. (4.6)
- Use appropriate scientific vocabulary to communicate ideas related to structure and bonding. (all sections)

Key Terms

bond dipole
central atom
covalent bond
covalent bonding
covalent network
crystal lattice
dipole–dipole force
hydrogen bonding
intermolecular force
ionic bond
ionic bonding
isoelectronic
London force
nonpolar bond
nonpolar molecule
polar bond
polar covalent bond
polar molecule
VSEPR

EXTENSIONS

hybrid orbital
hybridization
pi (π) bond
sigma (σ) bond
valence bond theory

Key Symbols

- $\sigma, \pi, \delta^+, \delta^-$

Problems You Can Solve

1. Predict the shape of simple molecules, using VSEPR theory. (4.4)
2. Predict the type of solid formed by a substance. (4.6)
3. Explain the properties of substances, based upon intermolecular forces and bonding. (4.5, 4.6)

MAKE a summary

- Intra- and intermolecular forces can be explained in a unified way by describing the central particle that is simultaneously attracted (electrostatically) to the surrounding particles. Complete the following table.

Force or bond	Central particle	Surrounding particles
covalent		
covalent network		
dipole–dipole		
hydrogen		
ionic		
London		
metallic		

- Each class of substance has a characteristic set of properties. Complete the following table using relative descriptions such as negligible, low, medium, and high. (Indicate n/a if not applicable.)

Substance	Hardness	Melting point	Electrical conductivity		
			Solid	Liquid	Solution
molecular					
ionic					
covalent network					
metallic					

Chapter 4 SELF-QUIZ

Identify each of the following statements as true, false, or incomplete. If the statement is false or incomplete, rewrite it as a true statement.

1. The shape of molecules of the rocket fuel hydrazine, $N_2H_{4(l)}$, is predicted by VSEPR theory to be trigonal planar around each nitrogen.
2. Diborane gas, $B_2H_{6(g)}$, is used to dope semiconductors. However, a Lewis structure cannot be drawn without modifying the theory; nor is a VSEPR diagram possible even though the compound exists, and is well known.
3. A central atom with two bonded atoms and two unshared electron pairs has a linear arrangement of its electron pairs.
4. Ionic substances are network solids, with a special type of metallic bonding.
5. Hydrogen bonding is possible whenever the molecule contains hydrogen atoms as well as N, O, and F atoms.
6. A molecule with a pyramidal shape and polar bonds will be nonpolar.
7. Larger atoms, like sulfur, can bond as central atoms in more ways than smaller atoms, like oxygen, because they have more complex electron structures.
8. Of the molecules HCl, HBr, and HI, the HI should have the highest boiling point.
9. The end of a soap molecule that attracts and dissolves oily dirt must be polar.
10. Covalent network solids generally have high melting points compared with molecular crystals.

Identify the letter that corresponds to the best answer to each of the following questions.

11. The Lewis model of the atom emphasizes the concept of
    (a) atoms gaining or losing electrons to become ions.
    (b) orbital hybridization.
    (c) electron energy level changes.
    (d) electron orbital overlap.
    (e) the stable octet of electrons.
12. The Lewis symbol for an oxide ion would show dots to represent
    ca) 2 electrons.
    (b) 8 electrons.
    (c) 10 electrons.
    (d) 18 electrons.
    (e) 32 electrons.
13. A Lewis symbol for an atom with a configuration of $1s^2\ 2s^2\ 2p^3$ would show
    (a) 1 unpaired electron and 3 electron pairs.
    (b) 2 unpaired electrons and 2 electron pairs.
    (c) 1 unpaired electron and 2 electron pairs.
    (d) 3 unpaired electrons and 1 electron pair.
    (e) 3 unpaired electrons and 2 electron pairs.
14. A Lewis structure for the molecule NCl_3 would show
    (a) 13 electron pairs.
    (b) 10 electron pairs.
    (c) 8 electron pairs.
    (d) 4 electron pairs.
    (e) 3 electron pairs.
15. X-ray diffraction evidence about the structure of compounds in crystals led to development of
    (a) structural models.
    (b) Lewis models.
    (c) VSEPR theory.
    (d) the octet rule.
    (e) energy level theory.
16. Which of the following molecules has a trigonal planar shape?
    (a) NH_3
    (b) CO_2
    (c) PCl_3
    (d) H_2O
    (e) BBr_3
17. Which of the following covalent bonds is the most polar?
    (a) N–O
    (b) C–H
    (c) O–H
    (d) H–Cl
    (e) C–Cl
18. The property that is best explained by intermolecular forces is
    (a) surface tension of a liquid.
    (b) electrical conductivity of a metal.
    (c) hardness of a covalent network solid.
    (d) melting point of an ionic solid.
    (e) the colour of copper.
19. Metallic bonding depends on
    (a) high electronegativity.
    (b) delocalized electrons.
    (c) polar covalent bonds.
    (d) electrical conductivity.
    (e) a full valence orbitals.
20. A molecule of a substance with physical properties primarily determined by London forces would be
    (a) SiC
    (b) KCl
    (c) Na_3P
    (d) PCl_3
    (e) H_2O_2

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their boiling points: $CH_{4(g)}$ (–164°C), $NH_{3(g)}$ (–33°C), and $BF_{3(g)}$ (–100°C). (4.5)

21. Ionic compounds and metals have different physical properties because of the different forces involved. For example, while sodium chloride and nickel have nearly identical molar masses, their melting points, conductivity, and solubility in water are quite different.
    (a) Explain the large difference in melting point between sodium chloride (801°C) and nickel metal (1453°C).
    (b) Predict the electrical conductivity of each of these substances in the solid state, and provide a theoretical explanation for your prediction.
    (c) Predict the solubility in water of each substance, and provide a theoretical explanation for your prediction. (4.6)
22. Name the forces acting between particles in each of the following substances:
    (a) hexane, $C_6H_{14(l)}$
    (b) 1-butanol, $C_4H_9OH_{(l)}$
    (c) ethylamine, $C_2H_5NH_{2(l)}$
    (d) chloroethane, $C_2H_5Cl_{(l)}$
    (e) calcium carbonate, $CaCO_{3(s)}$
    (f) diamond, $C_{n(s)}$ (4.6)

Applying Inquiry Skills

23. An investigation is to be done to see how well intermolecular force concepts can predict differences in solubility.

Question

What is the order from lowest to highest solubility in water for: pentane, $C_5H_{12(l)}$, 1-butanol, $C_4H_9OH_{(l)}$, diethyl ether, $(C_2H_5)_2O_{(l)}$, butanoic acid, $C_3H_7COOH_{(l)}$?

Prediction

(a) Predict the answer to the question, including your reasoning for each substance.

Experimental Design

(b) Design an experiment to answer the question. Include a brief plan and variables.

Materials

(c) Prepare a list of materials.

Procedure

(d) Write a numbered list of steps, including disposal instructions. (4.5)

24. Hydrocarbons can be oxidized step by step through a series of compounds until they are converted to carbon dioxide and water, e.g., methane (CH_4), methanol (CH_3OH), methanal (CH_2O), methanoic acid (HCOOH), carbon dioxide (CO_2). For each compound in this series draw a structural diagram, and then describe the molecular shape. (4.5)
25. Compare the particles and forces in the following pairs of solids:
    (a) metallic and covalent network
    (b) covalent network and molecular
    (c) molecular and ionic (4.6)

Making Connections

26. Methylamine, CH_3NH_2, is one of the compounds responsible for the unpleasant odour of decomposing fish.
    (a) Draw Lewis and structural diagrams for methylamine.
    (b) Use VSEPR theory to predict the shape around the carbon and nitrogen atoms in methylamine.
    (c) Methylamine and ethane have similar molar masses. Explain why the boiling point of methylamine is –6°C while that of ethane is –89°C.
    (d) Since amines are bases they react readily with acids. Use structural diagrams to rewrite the following equation for the reaction of methylamine with acetic acid:

$$CH_3NH_{2(aq)} + CH_3COOH_{(aq)} \rightarrow CH_3NH_3^+{}_{(aq)} + CH_3COO^-_{(aq)}$$

    (e) Explain how vinegar and lemon juice can be used to reduce the odour of fish. (4.3)
27. What material is used in the outer skin of a stealth bomber (**Figure 1**)? Describe how the structure and properties of this material relate to its function. (4.6)

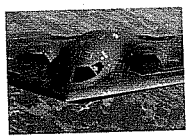

Figure 1

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Extension

28. Chlorine is a very reactive element that forms stable compounds with most other elements. For each of the following chlorine compounds, draw Lewis and structural diagrams, and then predict the polarity of the molecules:
    (a) NCl_3 (c) PCl_5
    (b) $SiCl_4$ (d) SCl_6

Unit 2 SELF-QUIZ

Identify each of the following statements as true, false, or incomplete. If the statement is false or incomplete, rewrite it as a true statement.

1. The term "orbital" refers to the path or trajectory an electron follows as it orbits a nucleus.
2. The configuration [Ne] $2s^2\ 2p^1$ represents an aluminum atom in its lowest energy state.
3. Rutherford knew that alpha particles were small and massive, and when moving fast should act much as bullets do when striking a target. He expected them to punch through his foil target and be slowed enough to let him determine the density of the atoms in the foil.
4. Light passed through a flame may have certain frequencies absorbed, because ions in the gas have electrons jump from lower energy levels to higher energy levels.
5. The ground state electron configuration for all alkali metals shows that the highest energy electrons are in a *p* sub-level.
6. There are thought to be seven *d* energy sublevels.
7. Spectra from atoms larger than hydrogen do not follow simple "rules" because when an atom has multiple electrons they repel each other and interfere with each other's orbital.
8. Schrödinger became famous by predicting that the particles called electrons might behave like waves under certain conditions, and then demonstrating this experimentally.
9. The aufbau principle states that when electron configurations are written, the lower energy levels must be filled before the higher levels.
10. VSEPR theory predicts that a sulfate ion, SO_4^{2-}, should be tetrahedral in shape.
11. VSEPR theory predicts that a central atom with three bonded atoms and one lone pair of electrons should have a trigonal planar shape.
12. A hydrogen bond is a particularly strong intermolecular bond existing between a hydrogen on one molecule and a lone pair of electrons on another molecule.
13. VSEPR and Lewis theories are not complete enough to explain the structure and shape of the molecules in gaseous uranium hexafluoride, $UF_{6(g)}$, which is used in uranium nuclear fuel-enriching processes.
14. VSEPR and Lewis theories are not complete enough to explain the structure and shape of the molecules in gaseous silane, $SiH_{4(g)}$, which is used as a doping agent in the manufacture of semiconductors for solid-state devices.
15. A molecule with tetrahedral shape and all bonds equally polar will be nonpolar, overall.
16. A three-atom molecule with linear shape and two identical atoms attached to the central atom will always be nonpolar.
17. Metallic bonding involves 3-D structures with vacant valence orbitals and mobile valence electrons.
18. Ionic bonding involves 3-D structures with vacant valence orbitals and mobile valence electrons.
19. Silver normally forms a 1+ ion, indicating that normally only one electron occupies its highest energy level.

Identify the letter that corresponds to the best answer to each of the following questions.

20. The atomic structure that did not follow directly from Rutherford's experiments is the idea of the
    (a) electron. (c) neutron. (e) "empty" atom.
    (b) proton. (d) nucleus.
21. Observing a frequency of light emitted by a hot gas will also allow prediction of a frequency that this same gas will absorb, when cool, according to theory advanced by
    (a) Rutherford. (c) Planck. (e) Chadwick.
    (b) Bohr. (d) Heisenberg.
22. The concept of atomic structure contributed by Niels Bohr is that
    (a) atoms can absorb and release only specific frequencies of electromagnetic radiation.
    (b) protons are extremely close together in a tiny part of the atomic volume.
    (c) electrons can have only certain specific different levels of energy.
    (d) electrons orbit a nucleus like tiny planets orbiting a star.
    (e) uncharged particles exist in the nucleus.
23. The biggest flaw in Bohr's theory was that it
    (a) did not apply to atoms larger than hydrogen.
    (b) predicted electrons would slow and spiral into the nucleus.
    (c) did not explain blackbody radiation.
    (d) predicted that protons in nuclei would repel and fly apart.
    (e) ignore the structure of the nucleus.

24. An energy-level diagram for fluorine would show the highest level of energy for
    (a) 7 electrons. (c) 10 electrons. (e) 19 electrons
    (b) 9 electrons. (d) 18 electrons.
25. The major differences in electron energy levels are described by the
    (a) principal quantum number, n.
    (b) secondary quantum number, l.
    (c) magnetic quantum number, m_l.
    (d) spin quantum number, m_s.
    (e) exclusion principle.
26. The concept that electrons are oriented along different axes in 3-dimensional space is described by the
    (a) principal quantum number, n.
    (b) secondary quantum number, l.
    (c) magnetic quantum number, m_l.
    (d) spin quantum number, m_s.
    (e) electron configuration.
27. The evidence that all substances are attracted or repelled by a magnetic field is described by the
    (a) principal quantum number, n.
    (b) secondary quantum number, l.
    (c) magnetic quantum number, m_l.
    (d) spin quantum number, m_s.
    (e) electron configuration.
28. The electron configuration of a chlorine atom in its lowest energy state is
    (a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$. (d) $s^2\ 2s^2\ 2p^6$.
    (b) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5$. (e) $1s^2\ 2s^2\ 2p^5$.
    (c) $1s^2\ 2s^2\ 2p^6\ 3s^1$.
29. The electron configuration of a calcium ion in its lowest energy state is
    (a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$.
    (b) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$.
    (c) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4\ 4s^2$.
    (d) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$.
    (e) $1s^2\ 2s^2\ 2p^6\ 3s^1\ 3p^5$.
30. The electron configuration that could be a fluoride ion in an "excited" energy state is
    (a) $1s^2\ 2s^2\ 2p^5$. (d) $1s^2\ 2s^2\ 2p^5\ 3s^1 4s^1$.
    (b) $1s^2\ 2s^2\ 2p^4\ 3s^1 4s^1$. (e) $1s^2\ 2s^2\ 2p^6\ 3s^1 4p^1$.
    (c) $1s^2\ 2s^2\ 2p^6$.
31. The idea of special stability due to the presence of a stable octet of electrons is central to
    (a) Kekulé line diagrams.
    (b) Bohr atomic structure.
    (c) VSEPR molecular shape prediction.
    (d) Pauling hybrid orbitals.
    (e) Lewis dot diagrams.
32. The Lewis symbol of a calcium ion would show dots to represent
    (a) 0 electrons. (c) 10 electrons. (e) 12 electrons.
    (b) 2 electrons. (d) 18 electrons.
33. The Lewis symbol of a magnesium atom would show dots to represent
    (a) 0 electrons. (c) 8 electrons. (e) 12 electrons.
    (b) 2 electrons. (d) 10 electrons.
34. A Lewis symbol for an atom with a most stable electron configuration of $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$ would show
    (a) 2 unpaired electrons and 2 electron pairs.
    (b) 1 unpaired electron and 3 electron pairs.
    (c) 2 unpaired electrons.
    (d) 1 electron pair.
    (e) 1 electron.
35. A Lewis symbol for a negative ion with a configuration of $1s^2\ 2s^2\ 2p^6$ would show
    (a) 3 unpaired electrons and 2 electron pairs.
    (b) 1 unpaired electron and 3 electron pairs.
    (c) 2 unpaired electrons and 3 electron pairs.
    (d) no electrons, either single or paired.
    (e) 4 electron pairs.
36. A Lewis structure for the sulfur dichloride molecule, SCl_2, would show
    (a) 3 electron pairs. (d) 12 electron pairs.
    (b) 4 electron pairs. (e) 18 electron pairs.
    (c) 10 electron pairs.
37. A Lewis structure for the hydroxide ion, OH^-, would show
    (a) 3 electron pairs. (d) 10 electron pairs.
    (b) 4 electron pairs. (e) 12 electron pairs.
    (c) 7 electron pairs.
38. The molecule in the following list that has a linear shape, according to VSEPR theory, is
    (a) H_2O. (c) CO_2. (e) CH_3COOH.
    (b) OF_2. (d) H_2O_2.
39. The hydrogen bonding of large molecules is a very important area of study in biochemistry. A hydrogen bond can only form at a location on a large molecule where a hydrogen atom is bonded either to an oxygen atom, or to
    (a) a nitrogen atom. (d) a sulfur atom.
    (b) a chlorine atom. (e) another hydrogen atom.
    (c) a fluorine atom.
40. The atoms of hard, brittle substances with high melting points are essentially all joined in a network of
    (a) ceramic bonds. (d) covalent bonds.
    (b) coordinate bonds. (e) hydrogen bonds.
    (c) metallic bonds.

Unit 2 REVIEW

Understanding Concepts

1. In Rutherford's classic experiment, it was found that most of the alpha particles in a directed beam passed through a metal foil essentially unaffected, while a very few of them were quite significantly deflected—some, almost straight backward. Explain what each part of this evidence indicates about the structure of the layers of atoms within the metal foil. (3.1)
2. Briefly outline the experimentation that led to the discovery of each of these subatomic particles:
   (a) the electron
   (b) the proton
   (c) the neutron (3.1)
3. Atoms of an element may differ in mass, and sometimes also in radioactivity.
   (a) Describe how this is explained as a result of structure within the atom.
   (b) State the term applied to such atoms. (3.1)
4. In 1900, classical theory suggested that warm substances radiating electromagnetic energy (like chemistry students) should emit mostly very short wavelengths. Thus, that theory predicts that people will radiate mostly ultraviolet light—but evidence shows they emit about 0.10 kJ/s, almost all of it as very long-wave infrared energy. Explain what Max Planck suggested as a way to deal with this evidence, which conflicted so dramatically with accepted theory. (3.3)
5. Rutherford suggested that electrons be thought of as orbiting a nucleus, like little planets orbiting a star. Explain why he assumed electrons could not be stationary—that is, why they somehow had to be moving around a nucleus. (3.3)
6. Bohr knew that according to electromagnetic theory, evidence clearly indicated that electrons could not really be travelling in circular orbits (or elliptical orbits, as Sommerfeld suggested) around a nucleus. Describe the evidence that would be observed if this were, in fact, the way electrons behave. (3.4)
7. Bohr had to ignore classical electromagnetic theory to make his own theory consistent. State Bohr's First Postulate, the first example of this break with tradition. (3.4)
8. The theory that electron energy change is quantized, that is, can occur only in specific amounts, is central to the development of Bohr's theory. State Bohr's Second Postulate, which establishes this concept. (3.4)
9. Draw an electron orbital energy-level diagram for each of the following simple atoms or ions:
   (a) nitrogen atom
   (b) sulfide ion
   (c) potassium ion
   (d) beryllium atom
   (e) zirconium atom (3.6)
10. Technetium metal (element 43) does not exist in nature because it has no isotope that is not highly radioactive. The metal is created in nuclear reactors as a fission byproduct of uranium radioactive decay, and can be obtained from spent nuclear reactor fuel. Based on an electron orbital energy-level diagram for technetium, predict whether it is attracted by a magnet, and explain what theory enables you to use the electron configuration to make this prediction. (3.6)
11. When water is poured into a glass, the bottom of the glass fills first, and when allowed to stand, the water surface becomes level. State which of these phenomena is similar to the application of the aufbau principle for electron configurations of atoms, and which is similar to Hund's Rule. (3.6)
12. The so-called transition elements, in Groups 3 to 12 of the periodic table (the "B" group), have chemical and physical properties that do not vary with the same simple periodicity as do those of "A" group elements. Explain why this is so, in terms of electron orbital configuration. (3.6)
13. Write a complete electron configuration for each of the following entities:
   (a) titanium atom
   (b) technetium atom
   (c) iron(III) ion
   (d) bromide ion
   (e) selenide ion (3.6)
14. Write a shorthand electron configuration for each of the following entities:
   (a) zirconium atom
   (b) mercury atom
   (c) radium atom
   (d) iodide ion
   (e) uranium(VI) ion (3.6)
15. State the maximum possible number of orbitals, and of electrons, in an *f* sublevel. (3.6)
16. Identify the following atoms or ions from their electron configurations:
   (a) atom : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^5$
   (b) 1^+ ion : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 4d^{10}$
   (c) 4^+ ion : (Xe) $4f^{14}$
   (d) atom : (Kr) $5s^2\ 4d^{10}\ 5p^1$
   (e) 2^- ion $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$ (3.6)
17. State the valence orbital and valence electron conditions that must exist on *each* atom, in order for an ionic bond to form between two approaching neutral atoms. (4.2)
18. State the primary factor controlling the packing together of ions (formation of the crystal lattice) in solid ionic compounds. What other factor(s) might affect the structure of the lattice? (4.2)
19. Describe the structural conditions that must apply on *each* molecule in order for a single hydrogen bond to form between two approaching neutral molecules. (4.2)
20. Draw Lewis symbols for atoms with the following electron configurations:
   (a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^4$
   (b) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^2$
   (c) [Ar] $4s^2$
   (d) [Kr] $5s^2\ 4d^{10}\ 5p^1$
   (e) [Xe] $6s^2$ (4.2)
21. Describe the physical and chemical properties of elements with electron configurations ending in $\#s^1$, where # is any integer from 2 to 6. (4.2)
22. Describe the physical and chemical properties of elements with electron configurations ending in $\#p^6$, where # is any integer from 2 to 6. (4.2)
23. Describe the chemical properties of elements with electron configurations ending in $\#p^5$, where # is any integer from 2 to 6, and explain why the physical properties cannot be generalized. (4.2)
24. Write out the words represented by the acronym VSEPR. (4.3)
25. Use VSEPR theory to predict the shape around the central atom(s) of the following molecules:
   (a) H_2O_2
   (b) SiF_4
   (c) NI_3
   (d) H_2S
   (e) CS_2 (4.3)
26. State which of the molecules SiF_4 and NF_3 should have smaller bond angles, and how VSEPR theory explains this. (4.3)
27. For the common substance found in household white vinegar—acetic acid, $CH_3COOH_{(aq)}$, do the following:
   (a) Draw the Lewis structure.
   (b) Use VSEPR theory to predict the shape around the three atoms that act as central atoms.
   (c) Draw a 3-D representation of the molecular shape.
   (d) Predict the polarity of each bond in the molecule, and whether the molecule will be polar overall.
   (e) Predict the predominant type of intermolecular bonding between acetic acid molecules in pure liquid state. (4.5)
28. The molecules H_2S and F_2 are isoelectronic. Explain what this means and what type of intermolecular bonding force may be predicted approximately for isoelectronic substances. (4.5)
29. Predict which of the substances $H_2S_{(g)}$ and $F_{2(g)}$ will have a higher boiling point; what this means in terms of the intermolecular forces present; and how VSEPR theory and electronegativity tables allow this prediction to be made. (4.6)

Applying Inquiry Skills

30. Write a brief experimental plan to distinguish the following pairs of substances. Identify the property to be tested and include a brief explanation of the principles involved in each test.
   (a) $He_{(g)}$ and $Ne_{(g)}$
   (b) $MnCl_{2(s)}$ and $ZnCl_{2(s)}$
   (c) $Zn_{(s)}$ and $I_{2(s)}$
   (d) $CaCO_{3(s)}$ and $SiO_{2(s)}$ (3.1)
31. Theories are valued for how well they explain and predict. Bohr's first and second postulates established the conditions necessary for his theory, but they were arbitrary statements, explaining nothing about themselves. State how de Broglie's concept of an electron considered as a standing wave *explained* Bohr's first and second postulates. (3.7)
32. Explain how de Broglie's theory removed the concept problem caused by the lack of observed electromagnetic energy radiation from any electron in any stable atom, which would naturally be expected from any *moving* negative particle. (3.7)
33. In an experiment to study a group of solids, each solid is rubbed across the surface of each other solid to see if a scratch mark occurs.
   (a) Identify the independent, dependent, and controlled variables.
   (b) What property of a solid is being tested?
   (c) How does this property depend on the nature of the particles present and the types of forces between them?